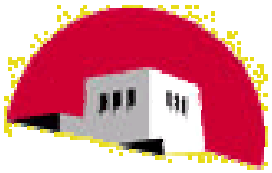

"The Importance of Ceramics in Pulsed Power Applications"

CDS October 2002 Meeting

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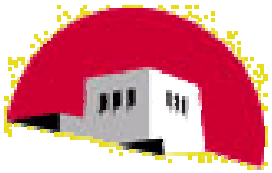
CONCLUSIONS

A revolution in pulsed power requires:‡

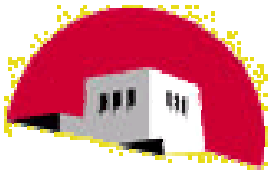
1) **High strength, high dielectric constant, high frequency components**
2) **Architectures that reduce the number of compression stages**
3) **Better switching**
4) **Diagnostics: nondestructive testing and active prognostics**
5) **Modularity**

‡ **Comments of Dr. Malcolm Buttram (Sandia National Laboratories) during the first annual review of the Compact Pulsed Power MURI program (portions of his talk are posted at: http://www.eece.unm.edu/cp3/HlywdReview0702/Presentations/PMC%20MURI%20talk.ppt)**



OUTLINE

- **Introduction to the Compact, Portable Pulsed Power MURI Program**
- **Quick tutorial on pulsed power, our interest in it, and its academic foundation**
- **Our particular interest in pulsed power: compact drivers for HPM**
- **Where ceramics can provide important advances in compact pulsed power for HPM**
- **Conclusions - How can we work together?**



Compact Pulsed Power MURI (UNM-Led Consortium)

Consortium Lead: Professor Edl Schamiloglu, UNM

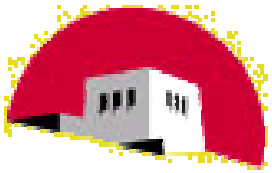
Consortium Partner: Professor Karl Schoenbach, Old Dominion University

Consortium Partner: Dr. Robert Vidmar, University of Nevada, Reno

Consortium Affiliates: Sandia National Laboratories (Gerold Yonas), Los Alamos National Laboratory (Mike Fazio), Air Force Research Laboratory (DE Directorate), Lockheed Martin Aeronautics Company (Steve Calico), and Diversified Technologies, Inc. (Marcel Gaudreau).

Program Began 1 June 2001, $1 M/year for up to 5 years.

http://www.eece.unm.edu/cp3/index.htm#
(our CP³ web site)



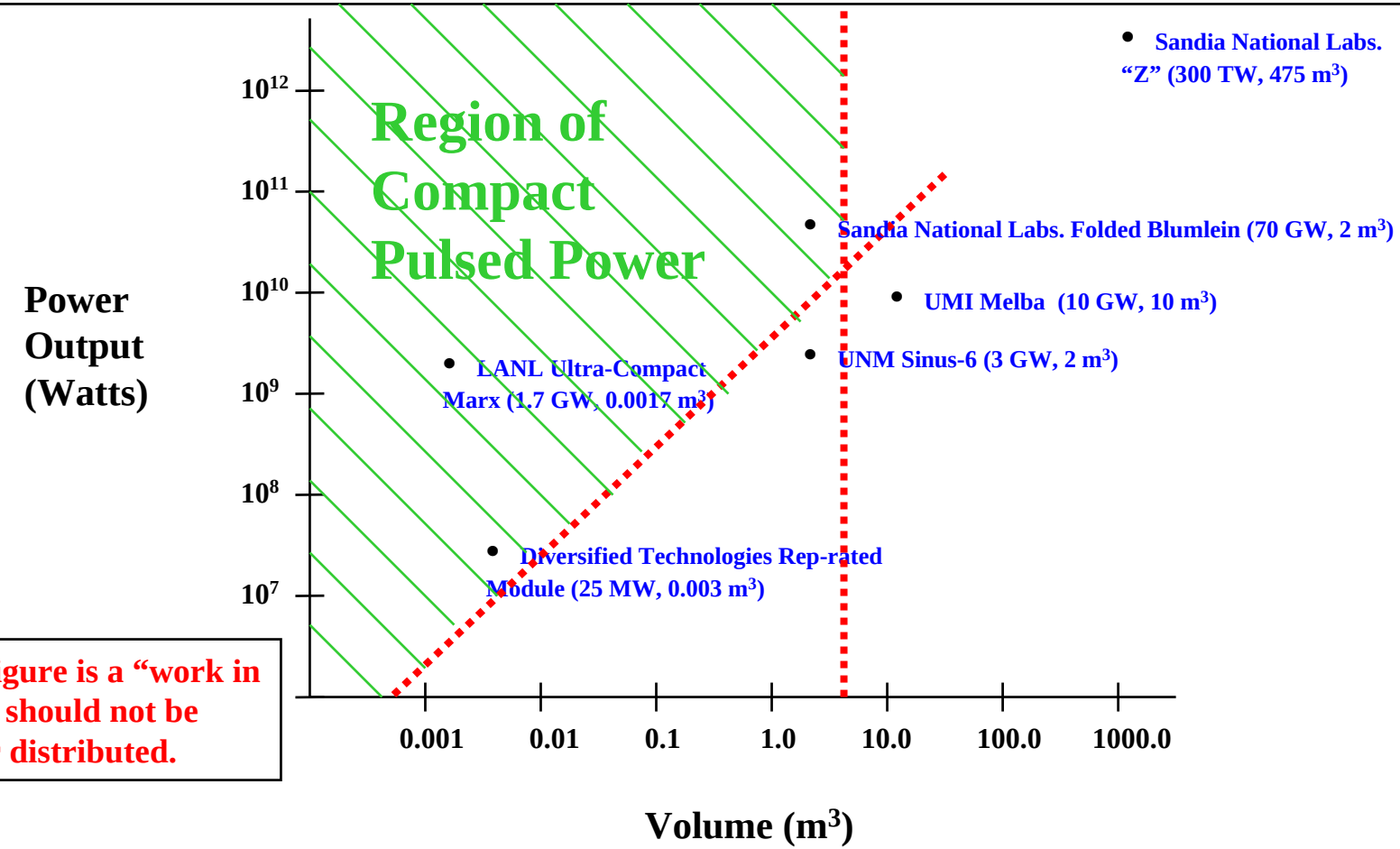
Pulsed Power Needs for DoD

	electrical energy	pulse length	peak pulse power	burst avg. power
• High power microwave	10 kJ	100 ns	100 GW	100 kW
• (Ultrawideband HPM systems)	10 J	1 ns	10 GW	10 kW
• (Particle beam self-protect)	100 J	1 us	1 GW	10 kW
• Electro-thermal chemical gun	1 MJ	10 ms	0.1 GW	1 MW
• Dynamic armor	1 MJ	1 ms	1 GW	1 MW
• Electromagnetic gun (rail and coil)	100 MJ	10 ms	10 GW	100 MW
• Electromagnetic launch and recovery	100 MJ	1 s	100 MW	1 MW

Slide courtesy of Dr. Malcolm Buttram (Sandia National Laboratories).

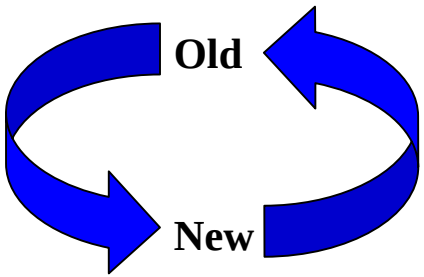
In general, there will be commonalities among the pulsed power needs for each of these two groups

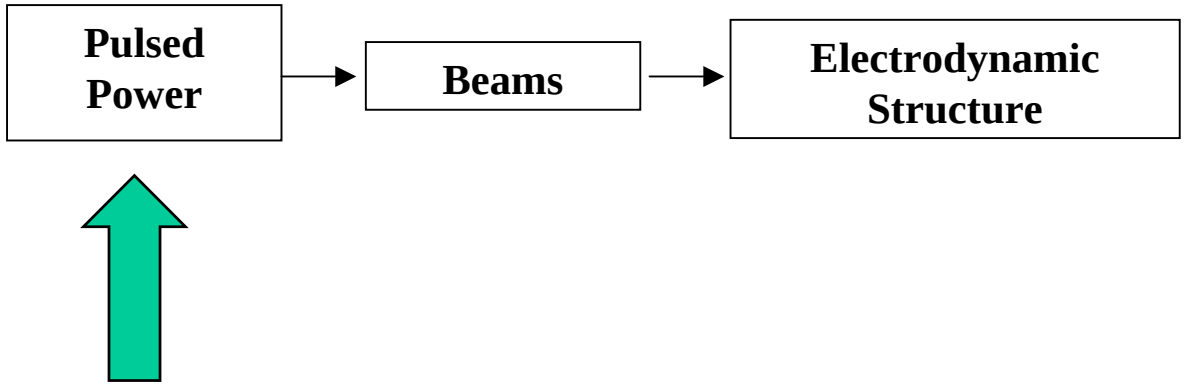
What is Compact Pulsed Power?



NOTE: This figure is a "work in progress" and should not be reproduced or distributed.

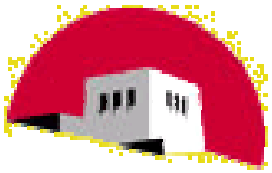
What is the UNM Consortium's Interest in Compact Pulsed Power?





Our present focus – new materials, sophisticated diagnostics, better modeling

Compact Pulsed Power for High Power Microwave Source Drivers

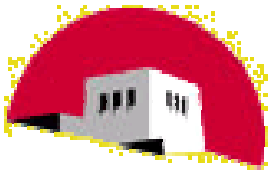


Definitions

<u>Pulsed Power</u> - imprecise term, typically denotes the combination of a capacitive energy storage system that is charged over a long period of time (time scale seconds), and that is rapidly switched to yield a high power pulse that is tailored and better matched to a load using a pulse forming line (final pulse width in nanosecond to microsecond range).

<u>High Power Microwaves</u> – imprecise term, usually denotes sources of coherent radiation spanning 1 GHz - >100 GHz at power levels scaling as Pf^2 driven by high-perveance, relativistic electron beams.

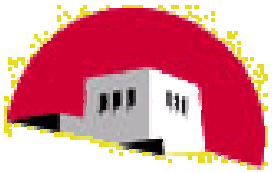
Pulsed Power is the technology used to generate the high-perveance beams to drive HPM sources.



Alternate Meanings

<u>Pulsed Power</u> - a) can mean rapidly switched solid state components, typically used to drive ultra-wideband sources. b) can include chemical explosive-generated voltage pulses (explosive flux compression generators).

<u>High Power Microwaves</u> – a) can mean high average power sources. A 10 kW average power tube is considered high power. A 100 kW pulsed power-driven tube is not very high power. b) can mean high power ultra-wideband microwave sources (not coherent, but broadband).



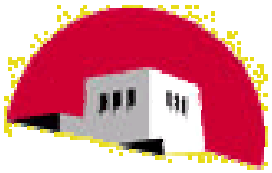
History of HPM Linked to History of Pulsed Power

<u>High Power Microwaves</u> "born" in late 1960's and early 1970's – Prof. John Nation (Cornell University) and Drs. Petelin, Kovalev* (Institute of Applied Physics, Gorky - Nizhny Novgorod, USSR, in collaboration with group in Moscow).

<u>Pulsed Power</u> – "modern pulsed power" attributed to Charlie Martin and colleagues at AWRE, Aldermaston in England in 1960's. Group interested in radiography had to use pulsed power to increase doses.

Some initial HPM sources revisited traditional microwave tubes, except used intense beams to drive them. Some HPM sources (e.g., the gyrotron) exist because of intense, relativistic beams.

Professor Kovalev was Distinguished Visiting Professor of UNM-EECE, June-July, 2002



How Do We Place HPM & Pulsed Power in an Academic Context?

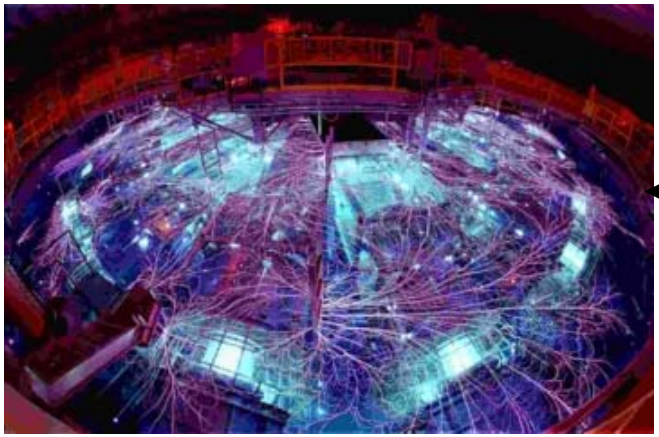
As an academic discipline, our research falls within the field of High Energy Density Plasma Physics Research (see National Academy of Sciences study, led by Ron Davidson, in progress: http://www7.nationalacademies.org/bpa/1rd.pdf)

- **Inertial Confinement Fusion**
- **X-Ray and Gamma-Ray Radiation Sources**
- **Plasma Accelerators**
- **High Power Microwaves**

Why is there Interest in High Energy Density Research?

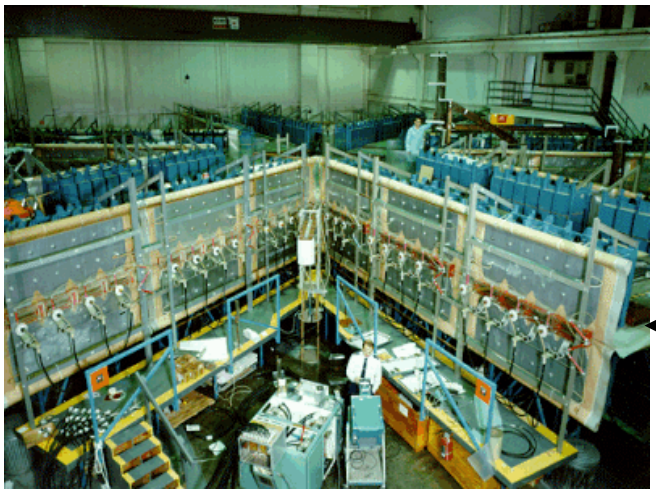
- **Stockpile Stewardship (DoE – radiation sources and ICF)**
- **Threats to the Infrastructure (General – "e-bomb")**
- **Fusion Energy Research (DoE – alternate energy source, HPM as ECR/LHD)**
- **Directed Energy Weapons (DoD – chemical lasers, HPM)**

Pulsed Power is the Enabling Technology for High Energy Density Plasma Physics Studies



The "*Z*" Pulsed Power Accelerator at Sandia National Laboratories

Explosive Pulsed Power Experiment at Los Alamos National Laboratory

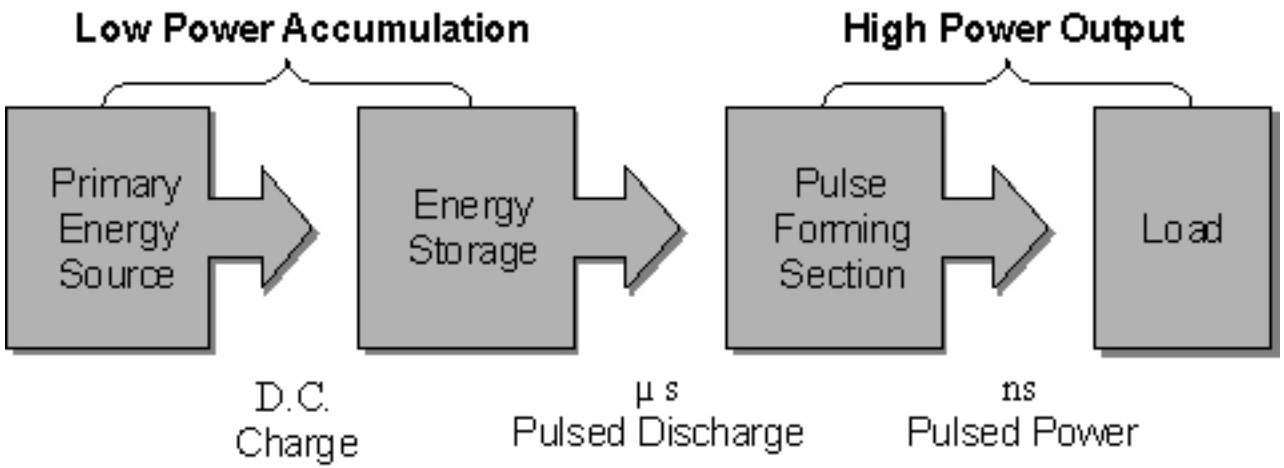


The Shiva-Star Pulsed Power Experiment at the Air Force Research Laboratory

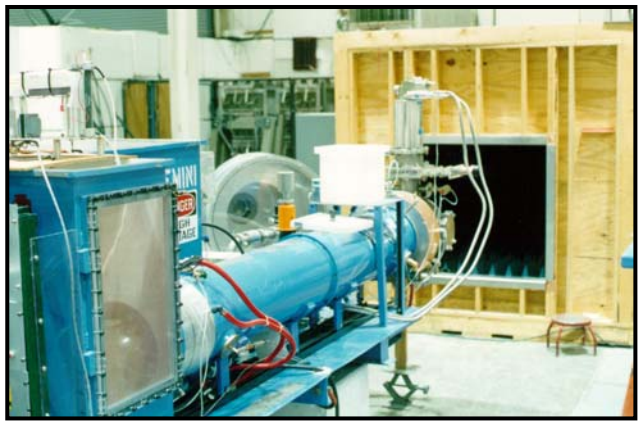
UNM is Located at the Hub of Pulsed Power Research in the United States

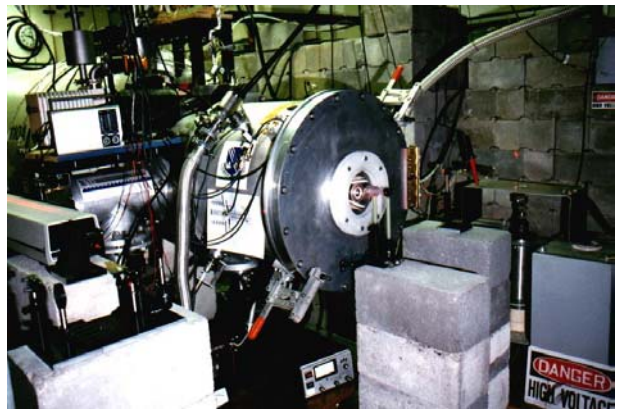
Pulsed Power for HPM

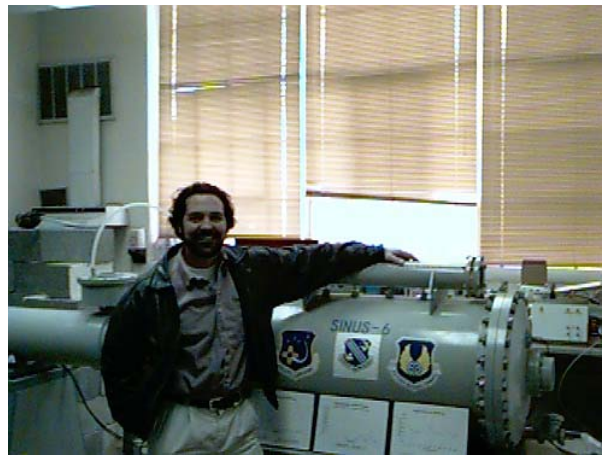
Capacitive Energy Storage-Based Pulsed Power Systems, Which Are …



… Typically Large and Massive (as can be seen in the HPM sources below!) ,



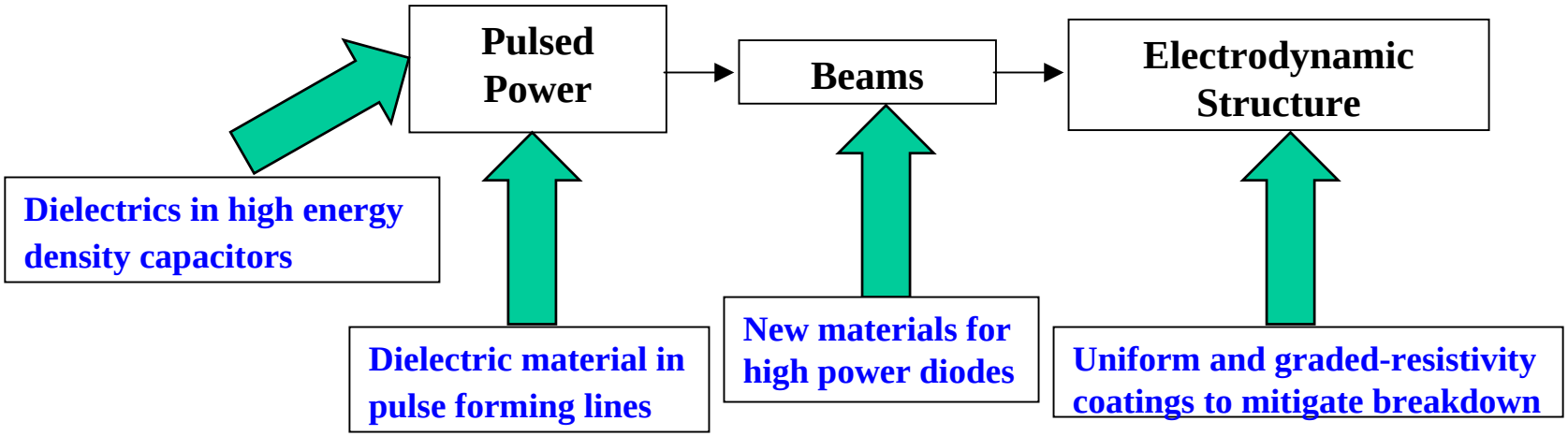




But Could Be Designed

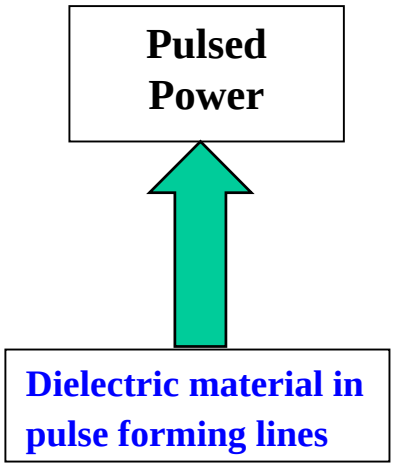
To Be More Compact!

Where can ceramics advance the state-of-the-art in pulsed power?



Compact Pulsed Power for High Power Microwave Source Drivers

Our immediate focus:

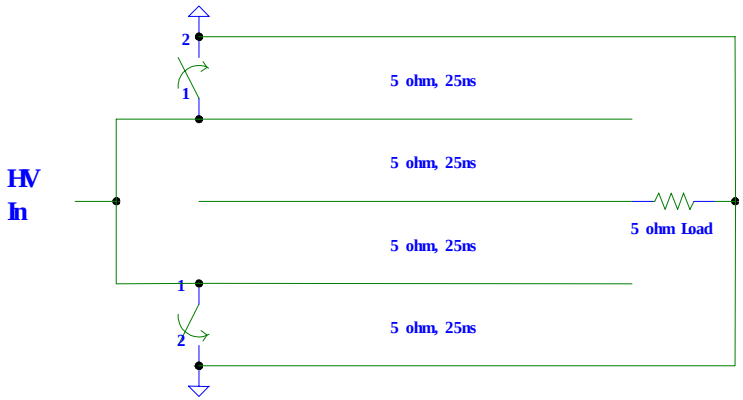


Compact Pulsed Power for High Power Microwave Source Drivers

What Is Required To Achieve This?

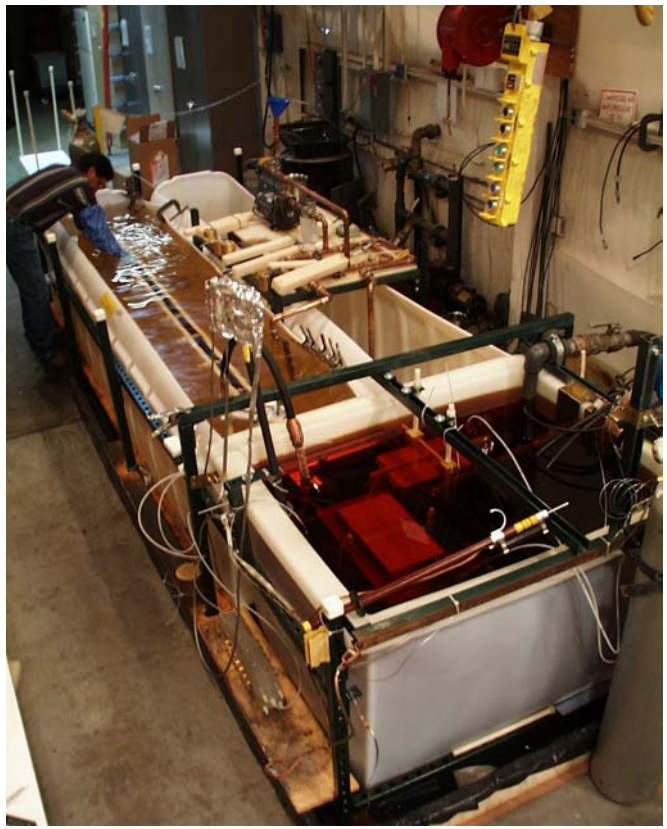
Basic Research In:

✓**Compact Pulsed Power Topologies (Folded Blumlein Pulsers Attractive – Research Ceramics and Liquids – Support AFRL/SNL Research)**



$$Z \approx \frac{377d}{w\sqrt{\varepsilon_r}} \ \Omega$$

WHY IS AFRL INTERESTED IN COMPACT BLUMLEIN TECHNOLOGY?



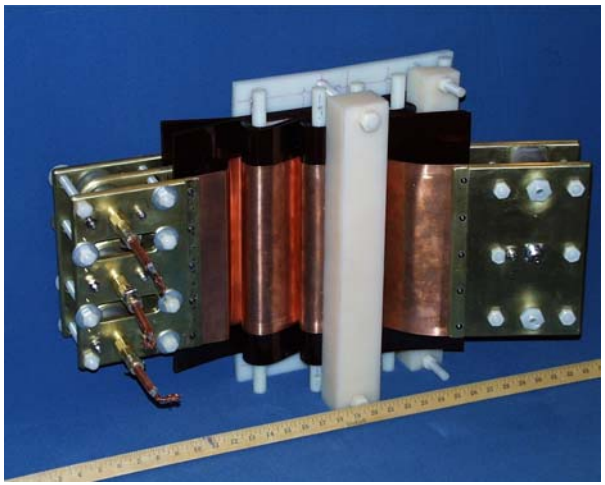
Compact folded Blumlein pulse-shaping driver being developed as a module to power an HPM source on an air frame.

Four technical problems being addressed by this MURI:

1) **Electrical breakdown at edges**
2) **Better switch required**
3) **Prebreakdown in propylene carbonate (w/ODU)**
4) **Research directed towards liquid free (ceramics) dielectric**

(Dr. Ron Pate, SNL and Dr. Tom Hussey, AFRL)

Present Approach: Folded Blumlein

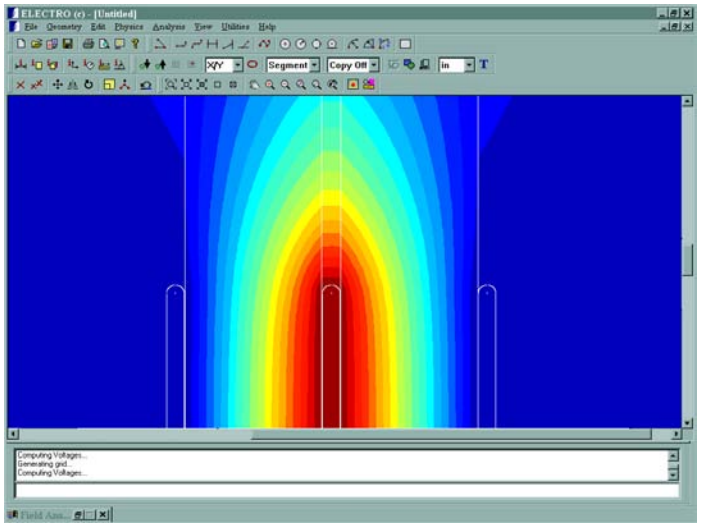


Problem: Electrical breakdown at edges

(48-inch Blumlein folded into a 15” assembly)

Courtesy Ron Pate

Extreme Electric Field at Edges

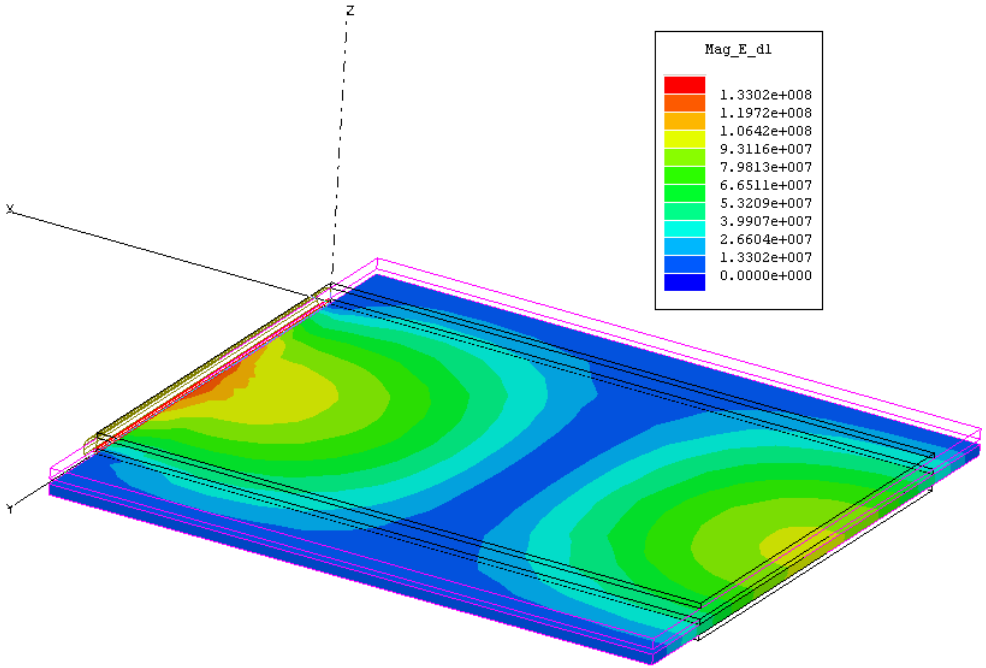


Electrostatic calculation of voltage contours at edge of Blumlein. Breakdown at the edge a problem.

A Steady-State Calculation

Dielectric Breakdown at the Edges of the Line

Results of HFSS™ (Agilent/Ansoft) calculation at UNM



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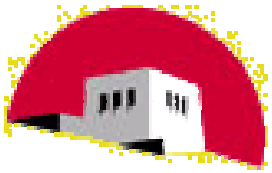


A More Desirable, Longer Term Approach Would Require High Energy-Store Dielectrics

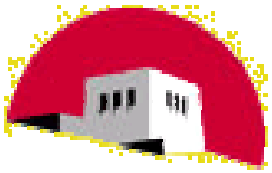
$$Z \approx \frac{377d}{w\sqrt{\varepsilon_r}} \quad \Omega$$

Increasing dielectric constant leads to more compact system with increased energy storage (no folding necessary)

$$W_E = \frac{1}{2}\varepsilon_0 \varepsilon_r E^2$$

$$t_{pulse} = L / v_{ph}, v_{ph} = c / \sqrt{\varepsilon_r}$$

Challenge: To identify such a material that has a high breakdown strength and can survive > 10^4 discharges.



Our Proposed Approach

1) use electromagnetic modeling tools to design resistively graded structure for use in Blumlein (UNM) (presently working on time-domain simulations to study single pulses on Blumlein)

2) work with ceramists to develop sample matrices

3) use pulsed high voltage tester to assess breakdown strengths (presently building such a pulser)

4) iterate with ceramists

Some of our Earlier Work with Ceramic Coatings

1) C.S. Mayberry, B. Wroblewski, E. Schamiloglu, C.B. Fleddermann, "Suppression of vacuum breakdown using thin-film coatings," J. Appl. Phys., vol. 76, 4448, 1994.

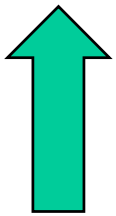
2) C. Grabowki, J.M. Gahl, E. Schamiloglu, and C.B. Fleddermann, "Pulse shortening in high-power backward wave oscillators," Proceedings SPIE , *Intense Microwave Pulses IV*, vol. 2843, 251, 1996.

NOTE: The idea of using a graded resistivity is not new. This has been used in the pulsed power community and is commonly used in the manufacture of capacitors. Peter and Zucker recently proposed applying a graded resistivity coating to high gradient rf structures in accelerators (W. Peter and O. Zucker, "Resistive-gradient coatings and high-voltage rf breakdown," submitted to J. Appl. Phys.).

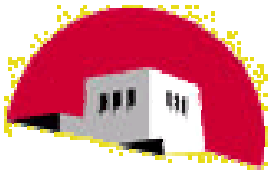
CONCLUSIONS

A revolution in pulsed power requires:

1) **High strength, high dielectric constant, high frequency components**



This is why I am attending this workshop.



ACKNOWLEDGEMENT

My UNM collaborators on this project are Marvin Roybal (EECE undergraduate), Miroslav Joler (Ph.D. student), Professor Christos Christodoulou and Research Professor John Gaudet. Our collaborators at Sandia National Laboratories include Mr. Jeff Alexander, Dr. Ron Pate, and Dr. Malcolm Buttram. Our supporters at the Air Force Research Laboratory (Directed Energy Directorate) include Dr. Peter Turchi and Dr. Tom Hussey.